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Slaking sensitivity of rocks – insights from a multi laboratory parameter study

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Abstract

The slaking behaviour of rocks is of geotechnical importance, affecting the stability of slopes and excavation pits, for example, as well as influencing the performance of underground excavation works, such as clogging of TBMs. Traditionally, wetting-drying and slake durability tests are performed to assess the degradation behaviour of weak rocks. Depending on their genetic origin, the slaking and disintegration behaviour of these rocks may exhibit different patterns. This study uses the results of widely used slaking tests, combined with the characterisation of disintegrated materials/decay products, to propose a tool for evaluating slaking sensitivity. Combining and extending the evaluation of these tests with mineral composition data and mechanical parameters enables a more detailed evaluation of the slaking behaviour of weak and soft rocks. Sedimentary rocks exhibit strong static slaking, whereas weak rocks derived from crystalline rocks slake under dynamic conditions. These findings have wider implications for estimating rock degradation in different geological settings and offer a quick laboratory method of estimating slaking rates and the potential liberation of fines, for example in the event of extreme precipitation.

Keywords

Rock Slaking, Soft Rocks, Rock Testing, Rock Decay.

1 Introduction

1.1 Background

Rock decay and softening occurs due to the action of external factors acting on the exposed rock, such as mechanical, or chemical weathering. One form of decay is slaking, referring to the formation of cracks and flaking, with associated degradationof rocks in the presence of water (Santi 1998). These processes affect all kinds of rocks, but the severity and intensity at which they act vary strongly. Usually, so-called soft rocks with a UCS <25 MPa (Kanji 2014) or weak rocks that react in the presence of water (Nickmann 2009) are mostly affected by external influences causing them to slake or change their consistency (Morgenstern and Eigenbrod 1974). However also hard rocks (usually grain bound crystalline rocks like igneous or metamorphic rocks) can suffer from slaking if their initial cohesive fabric is disturbed, for example by tectonic stress or advanced stages of weathering. Usually

standardized (laboratory) tests are being performed in order to assess the slaking behaviour and degradation characteristics. The disintegrating patterns after storing rocks for 24 hours in water after EN ISO 14689 areused as an initial classification of rocks into five grades. If the rocks exhibit grade 1 and 2, i.e. little to no reaction in water, the modified wetting-drying test (Nickmann 2009, Nickmann et al. 2025), or slake durability test (ASTM 2016, Herzel 2002) are being employed in order to account for long term changes. The latter imposes a dynamic action on the material by a rotating drum, while the modified wetting-drying test adds two additional cycles of 24 hours water storage and the grain size distribution is determined after the test is finished. In the present study, these widely applied tests and obtained parameters are further being used to compare the slaking behaviour of the rock material. The current study elucidates various aspects of rock disintegration and utilizes the combination of commonly used lab tests to propose a rating system for the slaking sensitivity.

2 Methods

A total of 71 samples were tested: 22 Miocene sedimentary rocks (clay and siltstones) were obtained from the St. Florian Beds in the Pre-Alpine basin region; and 49 samples of soft crystalline rocks and breccias (sericite phyllites, carbonate and sulphate breccias, low-strength micaschists, feldspar schists, tectonized gneiss and cataclasites) were obtained from the Wechsel region, a mountain pass in the Austrian Alps (Kaspar et al. 2025). Initially, on all samples wetting tests were conducted according to the ISO 14689 (ISO 2017) immersing the samples in deionized water for 24 hours at room temperature. Those rocks rated as Grade 1 or 2 were tested further under repeated static conditions in the modified wetting-drying test (WD_{mod}), but also under dynamic conditions in slake durability tests using a second set of sample material. The modified wetting drying test (Nickmann 2009) involves two additional wetting-drying cycles and sieving of the fragments and assignment of six degradation classes (VK classes). The slake durability index (I_d)isobtained from testing the rocks following the procedures described in the ASTM D4644 (ASTM 2016). In accordance with Recommendation No. 20 of the Commission on Rock Testing of the German Geotechnical Society, DGGT (Herzel 2002), resistant rocks are tested for up to six cycles (I_{d6}) or until more than 70% of the material in the drum has been lost. Finally, the bulk mineralogical composition of the material was determined using a PANalyticalX´Pert PRO diffractometer (CoKα radiation). From the clay mineral suspension (<2 µm) textured samples were retrieved. The analysis is performed in a Philips PW 1830 diffractometer (Cu Kα) following the procedure of the ON B 4810 (Austrian Standards International 2024). Uniaxial compressive strength (UCS) was determined on cylindrical specimen with a diameter to length ratio of 2:1 (typically diameter = 50±5mm, length = 100±10mm) using an MTS model 815. The tests are conducted load and/or strain controlled with a minimum duration of 5 minutes following the recommendation No. 1 of the DGGT (Mutschler 2004) and the Austrian standard ON B 3124-9 (Austrian Standards International 1986).

3 Results and Discussion

Selectedrepresentative specimen from the investigated rock types from the WechselSeries were tested for their UCS, showing low to moderate strength (Fig.1a & b). The early diagenetic clastic Miocene sediments from the St. Florian beds were assessed by the ISRM field procedure and estimated to fall into R0 to R2.The specimens were subject to water immersion following the ISO 14689 and graded accordingly (Fig. 2a). Out of the 71 initial samples selected for testing, 49 fell into the ISO 14689 grade 1 and grade 2 after 24 hours of immersion in water indicating no to little decay. Thus, these rocks were additionally tested in the modified wetting drying test and slake durability test. The grade 1 rocks also exhibit a high slaking resistance in the modified wetting drying test where the two additional immersion cycles in water did not substantially degrade the rock, and VK0 rocks comprise only those samples formerly assigned to grade 1. Only one sample from grade 1 rocks disintegrated enough to fall into VK 1. The VK0 class only comprised rocks from the WechselSeries and no Miocene clay-/siltstones. The grade 2 rocks showed a more differentiated behavior and are mostly classified as VK 2 to VK 3 (Fig.2a).After six cycles, none of the grade 1 rocks were found in the highest and lowest slake durability categories *very high* and *very low*, respectively (Fig. 2b). Decay of Grade 2 rocks was more pronounced and they are predominantly present in the lowermost categories. The rate of slaking and disintegration is higher for early diagenetic clay and siltstones compared to the weak, altered crystalline rocks. Especially between the second and the sixth cycle the increase in disintegration is lower for crystalline derived rocks. For example, the tectonized gneiss and clay-siltstone that exhibit a similar I_{d2} of ca. 60%, show a decrease until I_{d6} of 12% and 42%, respectively (Fig. 2c & d).

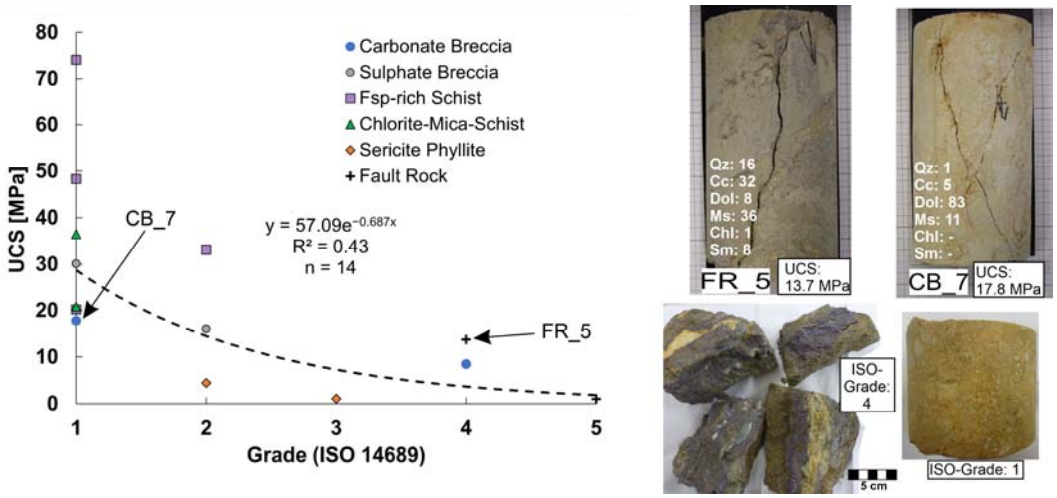


Fig. 1 UCS ranges across ISO grades (after Kaspar et al. 2025). Rocks that degrade stronger in water immersion tend to exhibit slightly lower UCS values. The strength is similar for the two samples shown, however, the slaking behaviour is different. The breccia (CB_7) contains little amounts of sheet silicates and no swelling clays sensitive to water, with a weak carbonate fabric, resulting in a low UCS. The fault rock (FR_5) contains water sensitive smectite leading to slaking, but exhibits a low strength in dry state as shown by UCS.

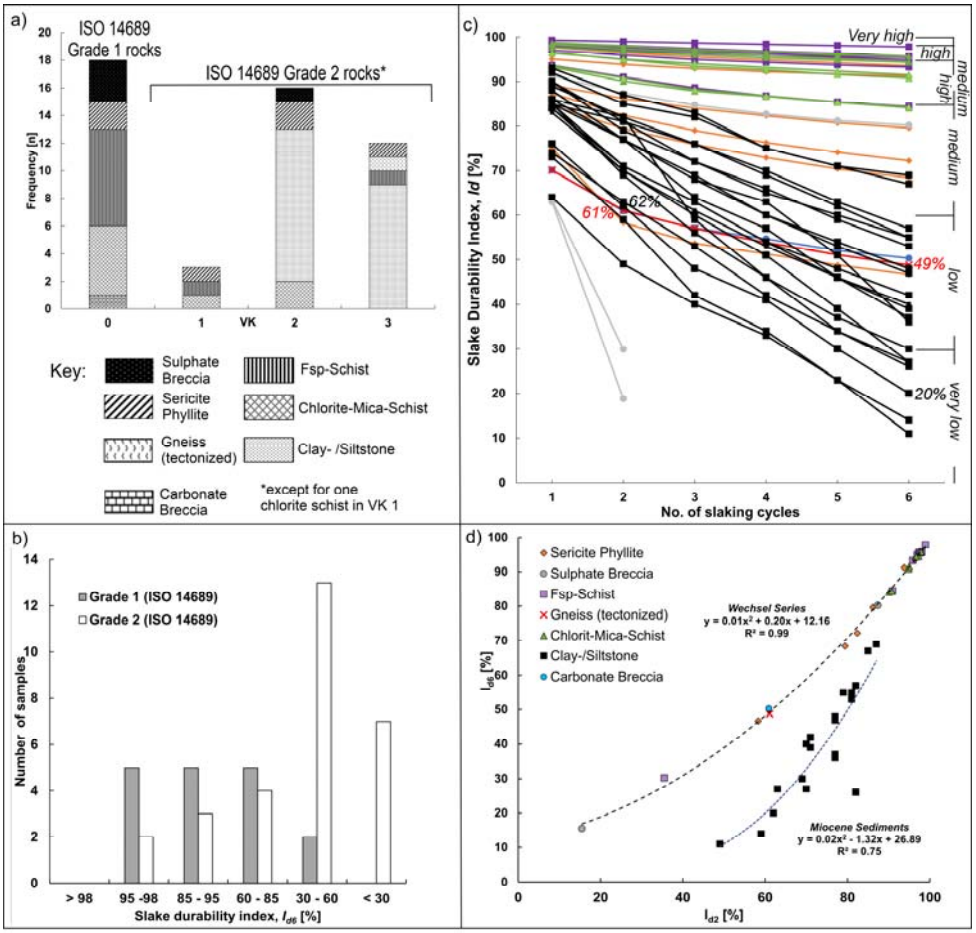


Fig. 2 Plots and diagrams of the wetting-drying and slake durability test results. a) Bar diagram illustrating the distribution of the different rock types according to their slaking classes in the (modified) wetting drying tests. b) Slake durability index classifications after Gamble (1971) within the ISO 14689 grades (from Kaspar et al. 2025). c) Evolution of the I_d over the cycles of the slake durability test; for legend see (d). d) Plot showing the correlation between the I_{d2} and I_{d6}.

The rocks of metamorphic origin with a diagenetic cohesive fabric usually do not exceed an increase of more than 15% between the second and sixth cycle. Exceptions are only sulphate dominated rocks, which did not survive mor than two cycles (i.e. loss >70%). Such rocks containing minerals sensitive to aqueous environments like anhydrite or gypsum are in general difficult or not well suited for slaking tests (Nickmann et al. 2025). However, the nature of disintegration is not obvious from the slake durability index alone (Fig. 3a & b). Therefore, the complementary visual assessment of rock

fragments retained in the drum after ASTM and DGGT is essential. Clay and siltstones exhibiting a strong increase in I_d, may be "2 (rounded)" according to the DGGT, referring to the shape of the pieces, but allow no statement on the fragment size. VK 2 rocks disintegrating in the WD_{mod} may not break apart during the slake durability test, forming downscaled pieces of the original lumps. This was observed for clay and siltstones where "mud balls" remained after the test(Fig. 3c & d). In contrast, rocks that did disintegrate (i.e. DGGT category 3) can still exhibit a relatively high slake durability index. In such cases the rock fragments are still larger than 2mm and thus retained in the drum, resulting in an apparently high slake durability. This was found for the crystalline derived rocks where platy or flaky pieces had formed.

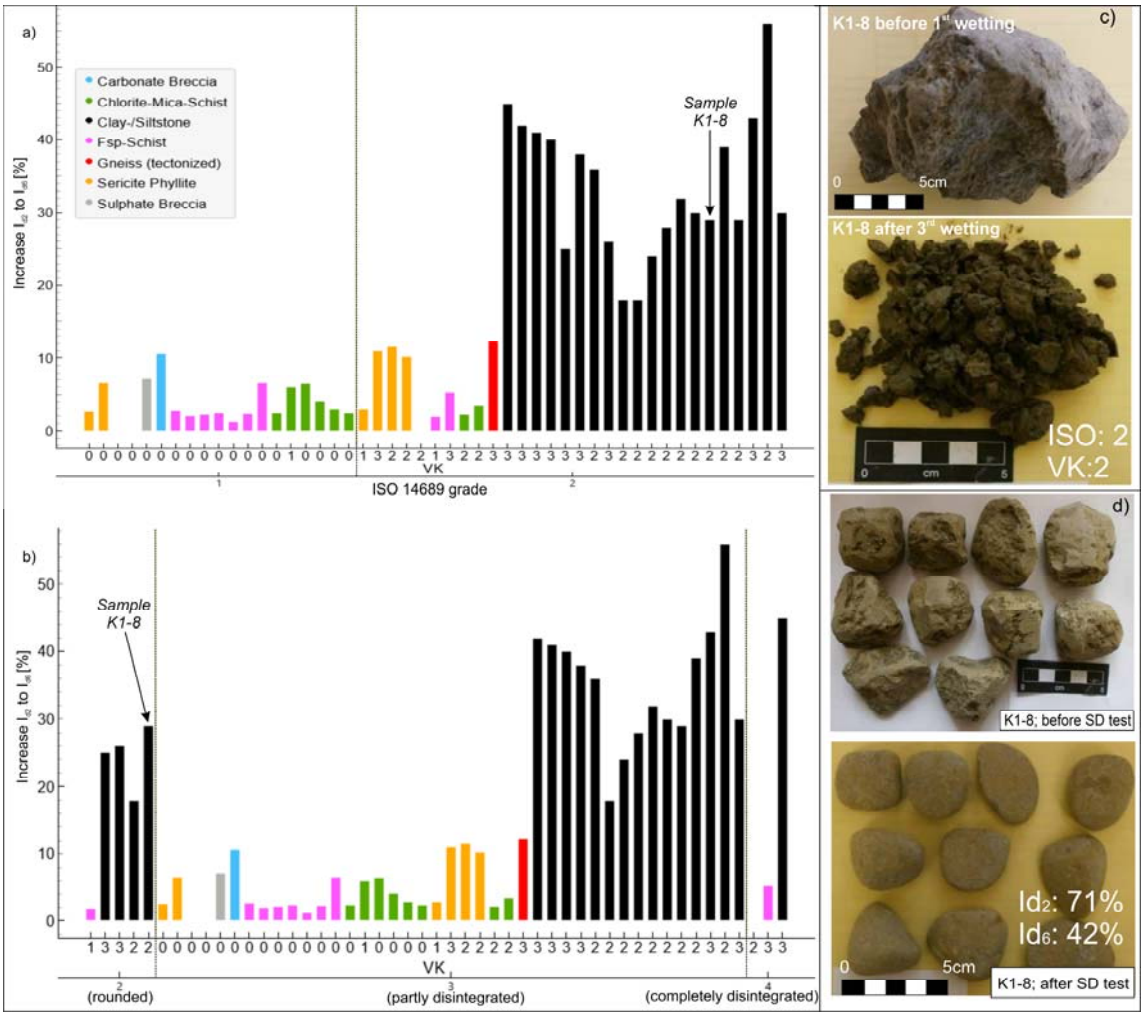


Fig.3 Increase of the slake durability index from the second to sixth cycle for the individual samples of the investigated lithologies (note that missing bars indicate samples that survived only two slake durability test cycles). a) Increase in I_d with respect to the associated ISO grades and VK classes. b) Increase in I_d with respect to the VK classes and DGGT categories. c) Sample K1-8 before and after WD_{mod}.d) Visual documentation of Sample K1-8 before and after slake durability test.

Mineralogically, sheet silicates are one common constituent of all rocks used for correlation. While the WechselSeries rocks contained typically muscovite (Ms) and chlorite (Chl), the clay and siltstones, have higher contents ofsmectite (Sm) and kaolinite (Kaol) (Table 1). The content of sheet silicates showed a negative correlation with the slaking behaviour expressed as the difference of I_{d2} and WD_{mod}(Fig. 4a). A positive or negative excess is determined by linking the $I_d$to the proportion $>2mm_{WDmod}$ (Fig. 4b). The slake durability test provides a simplified sieve analysis, since the material >2mm is retained within the wire mesh drum, expressed as I_d. The slaking sensitivity is the difference between the proportion >2mm from the sieve analysis conducted as part of the WD_{mod} and the I_{d2} or I_{d6}, respectively. If the value is very positive, the rock shows little to no reaction during water storage. However, dynamic slaking sensitivity is high, which is related to low UCS values for crystalline-derived rocks with a pre-damaged fabric, such astectonized gneiss.With higher UCS, crystalline rocks show essentially no slaking regardless of the number/duration of immersion cycles, thus plotting near the origin. If the value is very negative, the material already decayed strongly in the static test compared to the dynamic test as visible from the proportion >2mm of these samples (Fig. 5). The early diagenetic Miocene sediments show high static sensitivity, i.e. negative values, suggesting that the 24

hours of water immersion substantially damage the rock cohesion by water uptake and a change in consistency might occur. During the 10-minute cycles in the slake durability test, the material is capable of maintaining a certain internal cohesion or forms “mud balls” resulting in larger proportions of material >2mm, i.e. higher I_d values. Certainly, material decay progresses with increasing number of test cycles, but the six test cycles allow determining trends, rates and patterns of slakingbased on the amount of degradation occurring between I_{d2} and I_{d6}(Fig. 5). The Miocene sediments with very negative values exhibit low proportions of >2mm after water storage while othersshow delayed slaking under prolonged dynamic action.

Table 1. Ranges of mineralogical composition in percent of the rocks from this study.

Rock type	Quartz	Feldspars	Carbonates	Gypsum	Ms	Chl	Sm	Kaol
Sericite phyllite	9-35	0-11	3-45	0-5	20-36	1-19	0-1	0-1
Chlorite-mica-schist	15-39	0-17	0-16	-	32-83	34-70	-	-
Gneiss (tectonized)	30	32	4	-	32	1	-	-
Fsp-rich schist	24-30	7-22	2-15	0-32	18-70	14-21	0-1	0-1
Carbonate breccia	0-8	-	65-100	-	0-27	3-14	0-4	-
Sulphate breccia	4-39	0-7	0-43	12-32	16-47	0-19	0-2	-
Clay-/siltstone	11-29	0-13	0-30	-	42-66	0-15	1-10	0-7

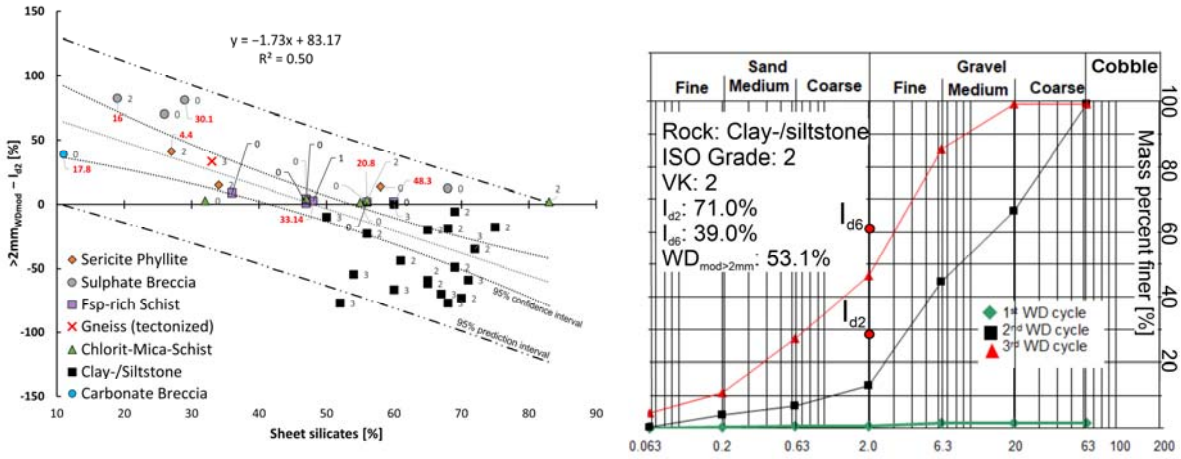


Fig. 4a) Effect of sheet silicate content on slaking type. Labels indicate VK classes. b) Sieve curve illustrating linking the I_d to the sieve curve of the WD_{mod}, i.e. fractions >2mm after the third WD test cycle (from Kaspar et al. 2025).

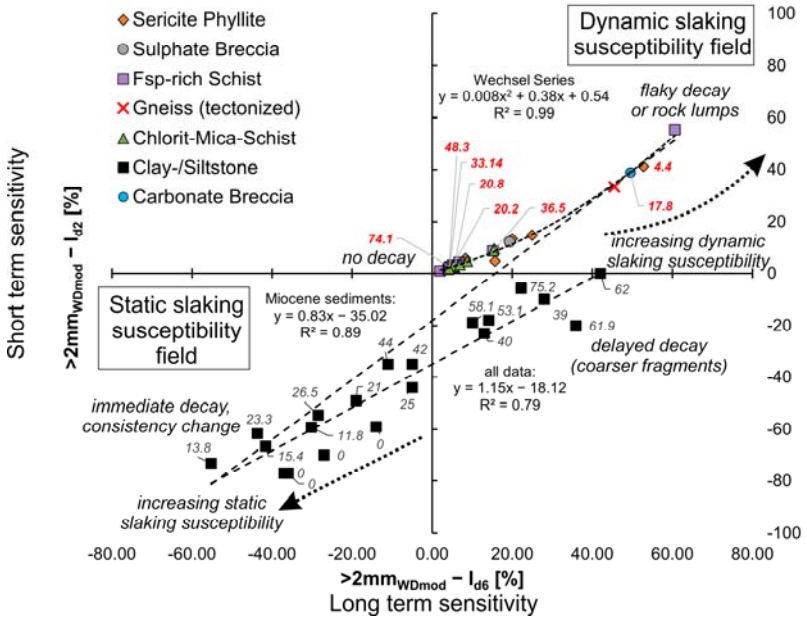


Fig. 5 Slaking sensitivity using modified wetting-drying tests and the slake durability test. (red datapoint labels = UCS; black datapoint labels =proportion>2mmWD_{mod}). The more sensitive the rock, the greater and sooner after immersion is the amount of fines released, i.e. low amount of >2mm and more negative values (adapted from Kaspar et al. 2025).

4 Summary and Conclusion

The combination of established slaking test supplemented by mineralogical analyses and UCS data allows a more differentiated evaluation of the slaking behaviour of rocks from different genetic geologic settings. Early diagenetic, non-lithified rocks slake stronger already under static conditions in aqueous environments, but may show a slaking pattern where the difference in fragmentation between WD_{mod} and slake durability tests is low, pointing to more resistance resulting in a delayed decay. The cohesion of non-lithified rocks can be moderate in a dry state, but water uptake can potentially lead to a change in consistency (e.g. mud balls). Weak rocks derived from lithified protoliths slake little under static conditions and require additional dynamic action to disintegrate substantially. The presence of sheet silicates points to strong mineralogical control on the slaking behaviour, but also the fabric and degree of lithification/ cementation and intergranular cohesionare critical.Other parameters, such as porosity, presumably also play a decisive role as a causative factor in slaking.For lithified rocks, the quality of the grain interlocking and associated UCS affect the slaking resistance in the long term where slaking occurs gradually via surficial flaky spalling rather than decay of the specimen as a whole. The presented diagram for linking grain size and slaking behaviour of the rock can be seen as a proxy for rate, intensity and sensitivity of slaking and used for identifying potential future hot spots or scenarios of intensified rock degradation accompanied by enhanced sediment /debris release. This can be, for example, extreme weather events, or geotechnical settings like soft ground, slurry-supported tunnelling, where liquids and dynamic forces (e.g. cutting wheel) act on the rock, in order to estimate the rates and intensity of potential fine material release. It should serve as an index for site investigations and further validation of its scalability and transferability to field applications will be necessary.

References

ASTM (2016) Standard test method for slake durability of shales and similar weak rocks (D 4644-16). ASTM International, West Conshohocken, PA, USA.

Austrian Standards International (1986) Testing of natural stone; mechanical properties of rock; modulus of elasticity, stress-strain curve and poisson's ratio under uniaxial compressive loading (ON B 3124-9). Austrian Standard International, Vienna, Austria

Gamble JC (1971) Durability-plasticity classification of shales and other argillaceous rocks. Ph.D. Thesis, University of Illinois, Urbana-Champaign, USA

Herzel P (2002) Recommendation No. 20 of the commission on Rock Testing of the Deutsche Gesellschaft für Geotechnike.V. – „slake-durability test“. Bautechnik (79): 101–105. https://doi.org/10.1002/bate.200200620

ISO (2017) Geotechnical investigation and testing — Identification, description and classification of rock (EN ISO 14689). Austrian Standards International, Vienna, Austria.

Kanji MA (2014) Critical issues in soft rocks. J. Rock Mech. Geotech. Eng. (6): 186–195. https://doi.org/10.1016/j.jrmge.2014.04.002

Kaspar M, Latal C, Pittino G, Reinprecht V (2025) Degradation and decay of rocks: linking wetting–drying and slake durability tests for climate-sensitive maintenance. Geotechnics (5):84. https://doi.org/10.3390/geotechnics5040084

Morgenstern NR, Eigenbrod KD (1974) Classification of argillaceous soils and rocks. J. Geotech. Eng. Division(100) 10: 1137–1156. https://doi.org/10.1061/AJGEB6.0000106

Mutschler T (2004) Uniaxial compression tests on rock samples – Recommendation No. 1 (revised) of the Commission on Rock Testing of the German Geotechnical Society. Bautechnik (81): 825–834. https://doi.org/10.1002/bate.200490194

Nickmann M (2009) Abgrenzung und Klassifizierung veränderlich fester Gesteine unter ingenieurgeologischen Aspekten. Münchner Geowissenschaftliche Abhandlungen, Reihe B - Ingenieurgeologie Hydrogeologie Geothermie, Heft 12; Verlag Dr. Friedrich Pfeil: Munich, Germany, 2009.

Nickmann M, Baumgärtel T, Plinninger R (2025) Determination of the slaking potential of rock using the combined method of wetting-drying and crystallization tests - Recommendation No. 27 by Commission 3.3. of the DGGT and Working Group 5.1.5 of the FGSV. geotechnik (48): 126–139. https://doi.org/10.1002/gete.202400039

Santi P (1998) Improving the jar slake, slake index and slake durability tests for shales. Environ. Eng. Geosci. (4): 385–396. https://doi.org/10.2113/gseegeosci.IV.3.385